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The Puncture Vine in California

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FOREWORD

Among the various weeds that are contributing to agricultural losses, in California, the puncture vine has rapidly become one of the most harmful. In certain counties it is causing enormous losses, and rendering almost worthless large acreages of valuable land. Moreover, it is spreading, the agencies responsible for its dissemination being many and difficult to control. But, the important point is that it *can* be prevented from spreading itself generally over the state if proper measures are followed.

This bulletin is a genuine contribution to the knowledge of the life history and habits of puncture vine and of practical methods for its control. It will be welcomed by those growers who now have infestations of the weed, and also by those who wish the information which will enable them to recognize the plant and to stamp out incipient infestations effectively.

Mr. Ethelbert Johnson, the author of this bulletin, is affiliated with the State Department of Agriculture. This organization plays a very active part in combating the weed problems of the state, particularly in enforcing the various regulatory measures which have for their purpose the prevention of the introduction and spread of noxious weeds. Its weed work is thoroughly organized. A number of agencies are cooperating with it in an attempt to solve the weed problems of the state. Although progress has been made, much is yet to be done along the lines of investigation, education, and regulation. Through the combined and organized efforts of all agencies concerned California may hope for a practical solution of her most acute weed problems.

W. W. Robbins,
Botanist, Experiment Station.

THE PUNCTURE VINE IN CALIFORNIA[1]

ETHELBERT JOHNSON[2]

ORIGIN, DISTRIBUTION, AND DISSEMINATION

The earliest reported collection of puncture vine (*Tribulus terrestris* L.) in California was made at Port Los Angeles in 1903 by Davidson,[(8)] who then commented on the species as "a probable permanent introduction from Arizona." Parish[(33, 34)] reports that it was "abundant" at Colton in 1908 and that "a few plants" were collected at San Bernardino the same year; he credits C. P. Fox with having found specimens at Bakersfield in 1905. Creditable observers state that puncture vine was in fact introduced into California some years before these collections. Thus Charles F. Collins, formerly Tulare County Horticultural Commissioner, recalls having first seen the plant at Dinuba in 1901; and some of the older ranchers in Kern and Tulare counties claim to have known it for about forty years.

Whatever the date of its original introduction, it did not apparently become abundant enough to attract much attention until about 1912, when Kent S. Knowlton, then Horticultural Commissioner of Kern County, recognized in it a potentially serious economic weed pest and sent specimens to the State Commission of Horticulture for determination. Essig[(9)] records that specimens from Placer County were received by the Commission, and that puncture vine was reported from Glenn County and from the coast side of the mountains west of the San Joaquin Valley before 1914.

From 1912 on, Knowlton[(27)] repeatedly called attention to the menace of puncture vine in the San Joaquin Valley, and urged that stringent measures be taken to stamp it out at any cost in areas where it occurred only as a light infestation.

Shortly after the creation of the State Department of Agriculture in 1919, the county horticultural commissioners assisted in a preliminary survey of the puncture vine situation in California. The distribution of the plant in 1920 was noted by Johnson[(16)] as follows:

> It has now spread over a large area in the Upper San Joaquin Valley, and is found in a nearly unbroken line along the railroads northward to San Joaquin County. In the Sacramento Valley it has been found at Woodland, Durham, and Marysville, and is reported as widespread along the railroads in Tehama County.

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[1] Received for publication, April 2, 1932.

[2] Deputy Agricultural Commissioner, Orange County, California State Department of Agriculture.

South of Techachapi the puncture vine is found from the Mexican border through the Imperial and Coachella valleys to the coastward valleys of Riverside, San Bernardino, Los Angeles, and Orange counties.

From the rapidity of its spread in the upper San Joaquin Valley in the last ten years it is to be expected that the pest will continue to extend its limits from these newer centers of infestation until something is done to check it.

At the time of this preliminary survey it was not known in the north coast counties, nor east of the Sierras; but by 1925 it had reached Glen Ellen in Sonoma County and Lone Pine in Inyo County, and in every subsequent year still further encroachments were recorded.

The year 1924 saw an especially heavy infestation of puncture vine. A series of conferences to determine whether the pest could not be better controlled by persistent statewide efforts led the State Department of Agriculture, in the fall of 1925, to offer a basic plan[(17)] which, with some modifications, was adopted in most sections of the state.[(18)] In some counties where puncture vine is not common, all infestations have been treated at county expense. In others the county has treated roadsides and county property only, private property owners being required to control their own infestations. In still other counties the roadsides have been systematically treated, but the only control measures practiced on private property have been voluntary. In only two or three counties where the infestations are exceedingly heavy have county roads not been treated. The State Highway Commission has practiced puncture-vine control throughout its extensive system, and the various railroads have cooperated in accordance with local practices.

The extent of the operations against puncture vine in California may be noted from the following figures,[3] representing the total expenditures by the counties for that purpose, exclusive of the cost of equipment, and not including amounts expended by individuals, by the railroads, and by the State Highway Commission: 1927, \$113,155.31; 1928, \$163,402.02; 1929, \$159,855.55; 1930, \$110,402.36.

Puncture vine is presumably a native of the Sahara Desert, whence it had spread throughout the Mediterranean region before the dawn of history. The early records of it in literature have been reported by Pickering:[(35)]

Tribulus terrestris of the Desert and its borders from the Atlantic to Hindustan and Lake Baikal. Called in Italy ''tribolo'' or ''Tribolo terrestre'' (Lenz), in Greece ''trivoli,'' or by the Turks ''demio dikieni'' (Sibth.), in Egypt ''Kharchoum el-nageh,'' or by the Nubians ''kenyssa kou'' (Del.), in tropical Arabia ''kotaba'' (Forsk.), in Egyptian ''sĕroji''—(transl. Matth.): the ''trivōlōs''

[3] From Annual Reports, California State Department of Agriculture.

is mentioned in the Septuagint translation of Hosea X.8, and in Matthew VII.16, as growing in Palestine: *T. terrestris* was observed by Delile in both Lower and Upper Egypt by Forskal p. 88 in Tropical Arabia, by Denham in Nigritia, and was received by A. Richard from Senegal and Abyssinia. Northward and westward from Egypt, the ''trivōlōs'' is mentioned by Aristophanes lys. 576; by Theophrastus VI.5 as having ''ěrěvinthōs''-like leaves; the ''trivōlōs hersaiōs'' by Dioscorides as growing about houses and along rivers; the ''tribulus'' by Virgil Geor. i.153, and as a weed in gardens by Pliny xvii 44 to xxii 12: *T. terrestris* is described by Lobal pl. 84, and Morison ii. pl. 8; is termed ''t. terrestris ciceris folio seminum integumento aculeato'' by Tournefort inst. 266; was observed by Desfontaines in Barbary; by Lenz in Italy; by Sibthorp, Chaubard,

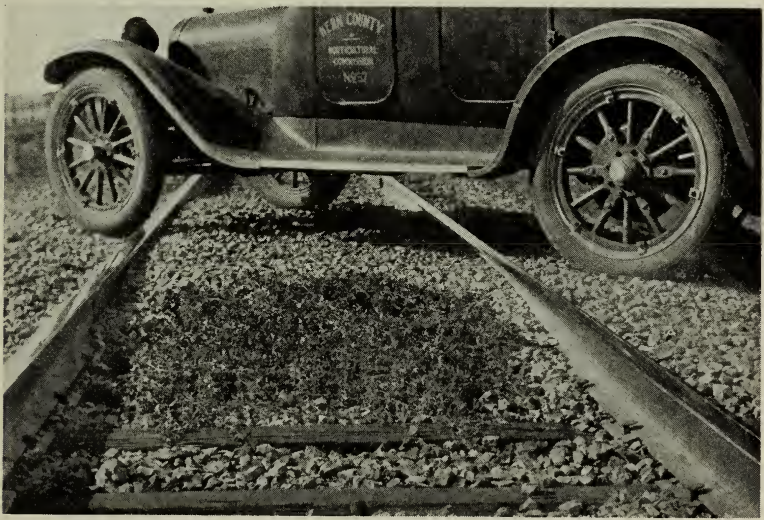

Fig. 1.—Puncture vine in ballast.

and Fraas, frequent in waste and cultivated ground from the Peloponnesus to the Dardanelles; is known to grow in southern Russia and from Caucasus along the border of Siberia as far as Lake Baikal (Ledeb.); was received by Fischer from Thibet; and was observed by myself, indigenous on the Deccan. In Austral Africa, may have arrived without European intervention; but clearly by European colonists was carried to the Mauritius Islands (Drege, Boj., and A. Dec.).

According to Georgia,[11] it was early introduced into the range lands of the middle western United States by the importation of livestock, especially sheep, from the Mediterranean countries, and is also found along the Atlantic seaboard. It is now abundant throughout the Southwest. The relation of the railroads to its introduction and distribution in California is apparent (fig. 1). Its rapid spread from those centers of infestation was concurrent with, and without doubt largely resulted from, the development of automobile travel in this state.

The automobile (fig. 2) has given the puncture vine a very much easier and more rapid means of dissemination than that afforded by nature; but although the automobile has been the chief means of spreading puncture vine locally, the railroads apparently have been responsible for most of the primary infestations; witness the fact that the first infestation in any locality has almost invariably followed the railroad right-of-way, usually in the vicinity of a stock-loading corral.

Fig. 2.—Ready dissemination of puncture vine by rubber-tired vehicles.

The burs are frequently carried in the wool or hair of animals, and are found in hay, straw, and other feed, in sand and other material used for bedding in stock cars, and in ballast hauled from infested gravel pits.

From a primary infestation, it may be picked up by automobiles (fig. 2) or by other means, and carried to roadsides, camps, parks, playgrounds, city streets (fig. 3), vacant lots, and agricultural land.

Once introduced into cultivated soil, it is readily picked up by implements and dragged through the field, and may be spread over a considerable area before its presence is realized.

The airplane is a new and potentially important means of bringing puncture vine into new localities by carrying the burs in its tires from one landing place to another.[29, 37] Agricultural products from

infested districts frequently carry the weed. Not only hay, straw, and manure, but melons, cotton, potatoes, and other products, and picking boxes, ladders, tents, and, in fact, almost anything else that comes in contact with the pest, are potential carriers.

DAMAGE FROM PUNCTURE VINE

The losses caused by puncture vine in California are unquestionably very high; but there is probably no basis on which the actual damage could be estimated.

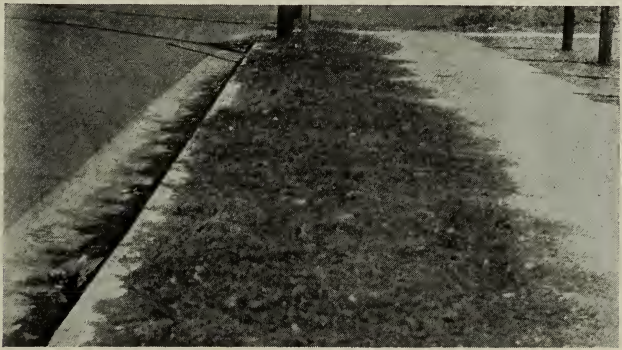

Fig. 3.—Puncture vine growing in parkway, Bakersfield.

Damage to Crops.—Puncture vine can readily be carried by various crops that come in contact with it. In many of the districts in which it is under control, shipments of potential carriers are inspected before delivery is permitted. Rejections of alfalfa and other hay, melons, grain, cotton-seed, milo maize, nursery stock, and cantaloupe seed have been recorded.

In cultivated crops puncture vine is especially troublesome, because its rapid growth, its long season, and its uneven germination make cultivation costs considerably higher. In crops such as melons, grapes, and cotton, which require hand work for harvesting, an infestation will increase the cost very materially; and in seasons when labor is scarce, pickers have sometimes refused to work in badly infested fields and vineyards. Jumper[25] quotes Wallace Sullivan, Kings County Farm Advisor, as follows:

> It costs probably $15.00 more per acre for cultivation where puncture vine has seriously infested fruit lands, and grape pickers fight shy of vineyards overrun with the barbed pest. Added cost of cultivation has been placed at $10.00 per acre with cotton and truck crops. Some cotton growers were forced to pay from one-quarter to one-half cent above the regular wage scales to get their crop picked

last year (1924), because of puncture vine infestations. Such cost amounts to from $3.75 to $7.50 per bale or from $6.00 to $12.00 per acre where a bale and a half of cotton was grown to the acre.

Losses to citrus fruits from decay in transit have also been traced to puncture vine in the orchard, where the picking sacks had been allowed to touch the ground and the burs had penetrated the skin of the fruit so as to permit decay fungi to enter.

In at least one case, puncture-vine burs have been found in bulk raisins purchased on the retail market.

Damage to Land Values.—The losses in valuation of land badly infested with puncture vine are difficult or impossible to estimate, but they are certainly very great. Some infested land is unquestionably not worth the cost of controlling the weeds. Banks are said to inquire into the practices of their clients as to puncture-vine control. Rental values in the San Joaquin Valley, according to C. H. Stiles of McFarland, as quoted by Jumper,[25] "dropped from the customary $25.00 per acre for good land to $18.00 or $20.00 per acre if puncture vine is allowed to overrun the place, and badly infested pieces depreciated in sale value as much as 25 per cent because of the infestation."

Injury to Persons.—The barefoot boy is almost unknown in sections where puncture vine is prevalent. Injuries to cotton and grape pickers are not uncommon. The handling of melons carrying puncture-vine burs has frequently resulted in injuries. Infections following puncture-vine wounds have occasionally been reported.

Injury to Animals.—The grade of wool is lowered by the presence of puncture-vine burs in large quantities. Mechanical injuries to animals as well as to persons are frequent. Cattle, horses, sheep, swine, and dogs have all been known to receive wounds from puncture-vine burs. Mouth injuries are occasionally noted, but not so frequently as might be presumed from the prevalence of the weed in certain sections. Harold L. Pomeroy, who, when Horticultural Commissioner of Kern County, worked closely with the county veterinarian and personally observed numerous cases of injury to livestock, stated in an unpublished report (1923):

> We found many instances where sheep had slowly starved to death, the cause of death being a mystery to the owner. They would not eat and would not seek food, but would lie down and slowly dwindle away. Examinations proved that the sheep had picked up mature burs in their feet, the prongs causing such a soreness that they could no longer walk. We found cases where both sheep and cattle had eaten these burs and had their stomach linings punctured. Horses have had their mouths so full of burs that they could no longer chew their food.

A disease of sheep in South Africa caused by grazing on green puncture vine is described by Stent.[40]

Authentic cases of serious injury to livestock in California from feeding infested hay are rare. In an investigation undertaken by Neville,[30] alfalfa hay containing large quantities of puncture-vine burs was fed for a period of eight weeks to six of each of the following animals: cows, calves, sheep, and hogs. No injury to any of the animals was noted, either during the time of observation or on post-mortem examination; nor was any loss of weight or condition noted that could be traced to the puncture vine.

Milk cows have been reported by dairymen to fall off materially in milk flow when first fed infested hay.

Fig. 4.—Prostrate, trailing habit of puncture vine.

Damage to Tires.—The spines on puncture-vine burs are stout enough to penetrate the tread of a pneumatic tire, and, if the tread is worn thin enough, can readily cause a puncture. Bicycle tires and well-worn fabric tires have frequently been punctured, but instances of punctures in cord or heavy balloon tires are rare. The spines probably do not penetrate into the tread much beyond their own length, as the working of the tire tends to pulverize them before they can damage the tube. Airplane tires, of lighter construction than automobile tires, have been reported punctured by burs on the landing field.[29]

DESCRIPTION AND CHARACTER OF THE PLANT

The name "puncture vine" or "puncture weed," generally adopted in California, is credited to Kent Knowlton, former Kern County Horticultural Commissioner. This name of itself has done much to keep the weed before the public mind. The earlier names by which it was known are "ground bur nut" and "caltrop." Other local names by which it is sometimes called include "Texas sandbur," "Texas longhorn," "bullhead," "Arizona thistle," and "heel-bur."

Puncture vine is thus described by Smiley:[39]

Habit: Mat-forming annual with many prostrate branching stems 10 inches to 2.5 feet long, conspicuously jointed, slender and weak, bearing short, silky, spreading hairs, or some of the stems ascending. *Leaves* numerous, compound, 1.5 to 2.0 inches long, formed of 5 to 7 pairs of leaflets, each leaflet about ¼ inch long, oval in shape and ending bluntly, grayish-green in color due to the covering of silky hairs on both surfaces; leaf-stalks short with a pair of small stipules at base. *Flowers* solitary in the leaf-axils, about ½ inch broad, short stalked; calyx of 5 persistent, jointed, hairy sepals; corolla of 5 yellow petals, longer than the sepals and broadening from the base, early falling away; stamens 10, alternately longer and shorter; ovary 5-celled, covered with erect hairs and surmounted by a short style ending in a 5-ridged stigma; the ovary ripening into a spiny fruit about ½ inch broad which at maturity splits into 5 parts (carpels), each containing 3 to 5 seeds and armed with 2 to 4 spreading, unequal and rigid, often curving spines, the longest ¼ inch in length.

The root system consists of a simple taproot branching into a network of very fine rootlets, which surround the soil particles so as to take the utmost advantage of the soil moisture. This root habit enables the puncture vine to live under conditions of drought survived by few other plants.

The stems radiate from the crown, branching freely. In open ground the habit is prostrate, exposing the maximum number of burs to the feet of passing animals or the tires of vehicles (fig. 4). Where the growth is very dense, the ends of the stems turn upward; and in the shade of alfalfa, the plant may grow almost erect; when growing along fences and other obstacles it may trail like a vine.

The leaves grow in pairs on opposite sides of the stem. They are composed of several pairs of small oval leaflets which give the plant such an attractive appearance that it has sometimes been carefully tended as an ornamental or lawn plant. The stems frequently have a reddish color; like the foliage, they are densely covered with silky hairs, which no doubt serve as a protective covering from heat and drought, and which give to the entire plant a silvery appearance.

The flowers, which are borne in the axils of the leaves, are bright yellow and add to the attractiveness of the plant. The petals are usually open only in the morning, closing shortly after noon, except in cloudy weather. The plant is therefore less easily found in the afternoon than in the morning.

The fruit (fig. 6) consists of a cluster of five of the spiny nutlets or burs by which the weed is best known. The nutlets, which fall apart at maturity, are adapted to dissemination by animals or rubber-tired vehicles because one of the two spines usually points upward whichever way the bur lies on the ground (fig. 5*A*).

Fig. 5.—*A*, The usual position of puncture-vine burs with one point upward; *B*, puncture-vine seedlings; *C*, burs cut open to show position of seed cavities; *D*, work of field mice on burs; *E*, fruit after treatment with oil; note the separation of the carpels (burs).

Fig. 6.—Green puncture-vine fruit.

The number of burs produced of course varies greatly with the size of the plant. Under exceptionally favorable conditions of soil, moisture, and light, plants have been known to reach a spread of 20 feet in diameter. A plant covering an area of approximately 400 square feet, observed by W. B. Camp at Shafter in October, 1923, was computed to have produced an average of 10 fruits per square inch, or a total of 2,880,000 burs. On the other hand, fully matured plants not more than 2 or 3 inches across may be found in hard, dry ground. A plant 3 months old observed by Paul L. Higley at Bakersfield in July, 1926, was found to have 820 mature bur clusters, 445 immature bur clusters, and 419 blossoms and buds.

The seeds, enclosed within the horny tissue of the bur, are protected by the spines and by the warty protuberances on the outer side of the nutlet or bur. Within the bur the seeds lie one above the other, separated by the same hard, horny tissue that composes the outer walls of the bur. The seed nearest the stylar end is the largest and usually sprouts first, the other seeds following in the order of their position in the bur. If there is sufficient moisture to germinate but one of the seeds in the bur, the others may remain dormant until conditions are favorable for germination.

The number of seed cavities in each bur varies from 1 to 4 (fig 5*C*). Of 25 burs taken at random from a sample, 10 were found to have produced 3 seed cavities each, all of which contained fully formed seeds; 10 were found to have 2 seed cavities each, 6 of these 10 burs containing 2 seeds each, 2 containing but 1 seed each, and 2 containing no fully formed seeds; 5 burs were found to have but 1 seed cavity each, 2 of these burs each containing a fully formed seed, and 3 containing none. The average number of seed cavities in the sample was 2.20 per bur; the average number of fully formed seeds, 1.84. Five burs, or 20 per cent, contained no fully formed seeds. In a duplicate sample incubated in the laboratory 72 per cent of the burs tested germinated one or more sprouts each.

LIFE HISTORY

Season of Growth.—The normal period of growth of puncture vine is from late spring until fall, the beginning of the period of active growth varying from year to year. Growing plants have, however, been found in all months, although they are very susceptible to frost. Thus specimens were collected at Terminal Island, Los Angeles County, on January 12, 1927, and at McPherson, Orange County, on February 24, 1930.

For four seasons, 1923–1927, F. R. Brann kept a record of the number of plants that sprouted under natural conditions on a vacant lot at Visalia (table 1). No plants were allowed to form seed during this period. The lot, 200 by 150 feet, was in a generally moderate degree of infestation for several years before 1922. In April, 1922, the lot was cleared of weeds, and thereafter the puncture vine was hoed and burned four times during the season, no check being made as to the number of plants destroyed. Beginning in May, 1923, the young plants were pulled by hand at frequent intervals, and a record was kept of the number found and destroyed upon each inspection. Since 1927, parts of this lot have been used for testing various treatments, hence further data on the number of plants recurring over the entire plot under natural conditions are not available.

TABLE 1

Seasonal Growth of Puncture Vine in a Plot 200 By 150 Feet Under Natural Conditions, at Visalia, California, 1923–1926*

Year	Date	Number of plants destroyed	Year	Date	Number of plants destroyed
1923	May 16	482	1925	May 15	715
	June 1	276		May 28	305
	June 18	258		June 10	229
	July 7	391		June 27	137
	July 20	88		July 8	12
	July 29	32		August 12	91
	August 12	9		September 2	5
	August 31	16		September 24	3
1924	May 6	126	1926	April 13	6
	May 30	585		April 28	518
	June 12	816		May 13	348
	June 23	184		May 29	213
	July 7	217		June 10	192
	July 20	123		June 25	316
	August 3	87		July 6	213
	August 18	112		July 12	87
	September 20	52		July 23	12
	October 2	9		July 27	3
				July 29	5

* From data compiled by F. R. Brann, Tulare County Horticultural Commissioner.

The accumulated germination as shown in table 1 was compared with the mean temperatures at Visalia for the corresponding periods, the temperature data being calculated as accumulated temperatures above 55° F, beginning with April 1 of each season.

The trend of the germination curves followed the accumulated temperature curves with remarkable regularity through the month

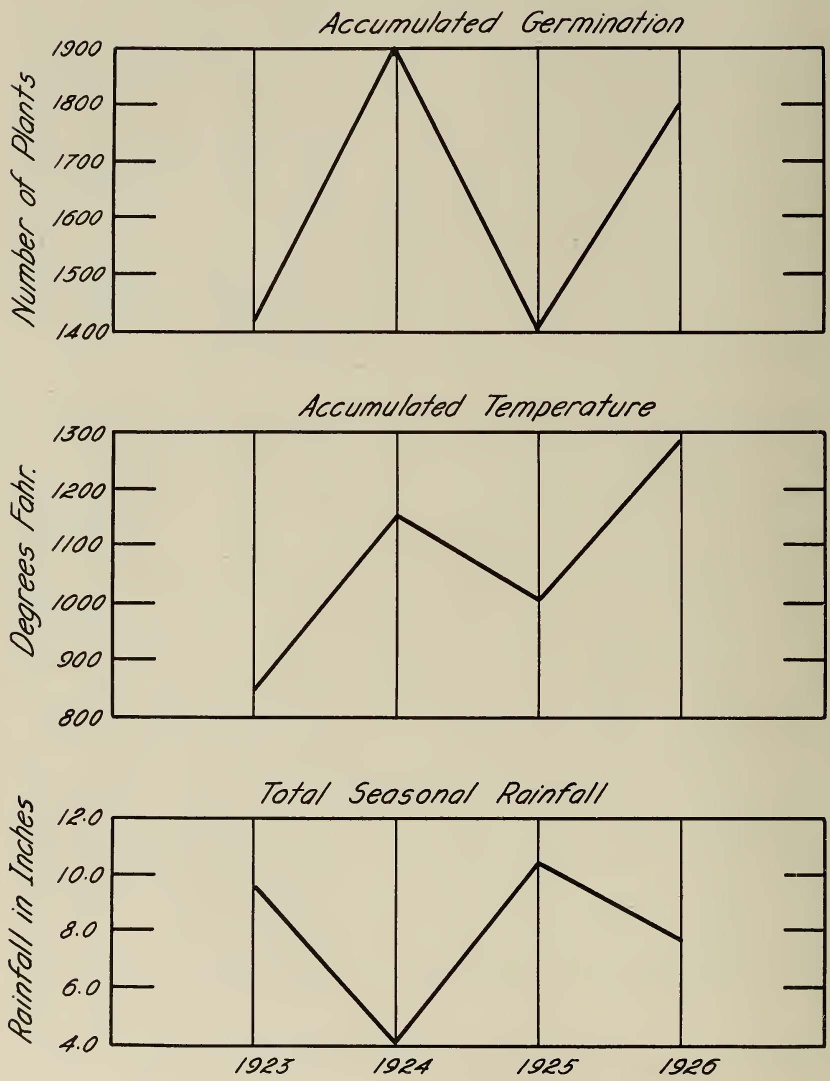

Fig. 7.—Effect of May and June temperatures upon the seasonal germination of puncture vine under natural conditions at Visalia, 1923–1926, inclusive. The upper curve indicates accumulated germination of puncture vine to July 15 of each season on a plot 150 by 200 feet. (Compare table 1.) The center curve indicates accumulated temperatures above 55° F for the months of May and June of the corresponding season. The lower curve indicates rainfall.

of June, when they diverged widely. The correlation between the accumulated germination for May and June of each season, and the accumulated temperatures for the same period, as shown in figure 7, is very high ($+0.907 \pm 0.027$). During that period of each year the soil moisture was presumably sufficient for germination, provided the temperatures were favorable. When the mean temperatures in these two months were relatively high, in 1924 and 1926, the rate of germination was rapid; and when the May and June temperatures were relatively low, in 1923 and 1925, the rate of germination was slower. In each case the rate of germination fell off sharply about the middle of July, approximately 90 per cent of the total number of plants for the season having sprouted by that time, a fact indicating depletion of soil moisture.

There is no apparent correlation between total seasonal rainfall, practically all of which occurs in the winter months in that locality, and the germination of the puncture vine. The two years of high total germination, 1924 and 1926, were both seasons of low rainfall. However, repeated observation show that puncture-vine seed can be made to sprout in abundance if sufficient moisture is provided during the warmer months. Thus rains in southern California in August, 1927, and again in September, 1929, followed by warm temperatures, caused the sprouting of multitudes of puncture-vine seeds which normally would have remained dormant until the following season. The concurrence of late spring rains and abnormally high temperatures in 1931 made the puncture vine that year more abundant than ever before.

Longevity of Puncture-Vine Seed.—Little is known as to the probable life of puncture-vine seed. Darlington[7] records that the seeds of many common weeds are capable of remaining alive and germinating after lying buried in the soil for over forty years. One may reasonably assume that the seeds of puncture vine, with their resistance to heat and drought, are at least as long-lived as the seeds of most other weeds. The Visalia plot (table 1) showed no diminution in the number of plants appearing each year for a period of four years, other than might be explained by seasonal variation. Subsequent observations of a part of the same plot that has remained undisturbed for five years longer indicate that to date (1931) an abundance of viable seed still remains in the soil.

Maturity and Seed Production.—During the normal growing season, the plants mature very rapidly. A plant under observation by W. B. Camp, at the United States Cotton Field Station at Shafter in 1926, averaged one blossom a day on each branch during the most

active period of growth. The blossoms were tagged and dated, and samples were collected of burs of various ages from the time of blossoming. These samples were held until the following season and germinated in the laboratory (table 2). The least mature sample to germinate was 10 days old, while the sample 11 days old germinated nearly as well as fully matured seed. The variations in the germination tests for the various samples no doubt result chiefly from the small number of burs in the sample. The 8, 9, and 10-day samples decayed after 7 days in the incubator, while the others continued to germinate for a longer period.

The rigidity of the spines roughly indicates the stage of maturity. The spines of young burs are soft and flexible, not sharp to the touch; they gradually become sharper and more rigid as the seed approaches maturity. A sample of burs collected from plants at Colton in July, 1922, at the stage when the spines were still fairly flexible and the points just beginning to feel sharp, when tested in 1925 germinated 2 out of 25 burs, or 8 per cent.

TABLE 2

GERMINATION TEST OF PUNCTURE-VINE BURS OF VARIOUS AGES FROM THE TIME OF BLOSSOMING, COLLECTED AT SHAFTER IN 1926*

Age, days	Number of burs in sample	Number germinated	Per cent germination	Length of test, days
8	19	0	0	7
9	24	0	0	7
10	17	1	6	7
11	20	15	75	12
12	21	17	81	12
13	16	12	75	12
14	17	15	88	12
15	16	15	94	12
16	15	13	87	21
17	7	3	43	21
18	9	5	56	21
Ripe	64	55	86	28

* Collected by W. B. Camp.

Germination.—Puncture-vine seeds sprout most rapidly during the warmest weather, moisture and other conditions being equal. A number of samples in different stages of maturity were tested in duplicate to determine the effect of temperature on germination. One lot from each sample was incubated at a day temperature of 30° C (86° F) and a night temperature of 20° C (68° F). The other lot was incubated at a day temperature of 35° C (98° F) and a night temperature

of 20° C. In every case the lot incubated at the higher temperature showed a more rapid rate of germination and a higher total number of sprouts. The results are represented graphically in figure 8.

An appreciable difference in the rate of germination may be noted between burs picked before shattering, newly matured burs, and mature burs from the previous season. A further check made on a number of burs in different states of maturity indicates that germination is very rapid in seed one year old or more. Approximately 90

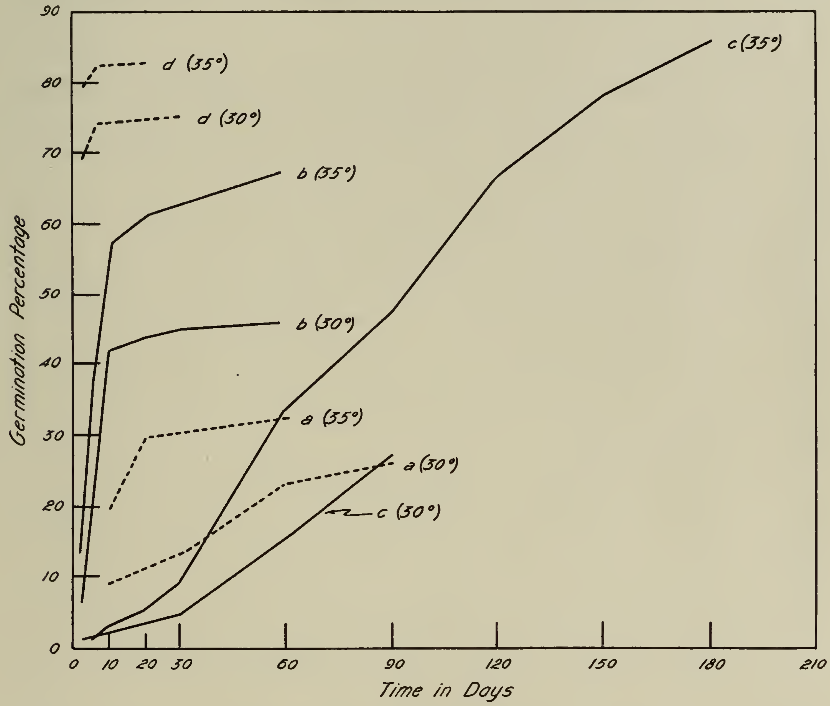

Fig. 8.—Rate of germination of typical samples of puncture-vine burs in different states of maturity, as influenced by temperature. Heavy lines indicate lots incubated at day temperatures of 35° C and night temperatures of 20° C. Light lines indicate lots incubated at day temperatures of 30° C and night temperatures of 20° C. *a,* Burs picked before shattering; *b,* same, dried before incubating; *c,* burs shattered, current season; *d,* burs one year old.

per cent of the number of viable burs of such seed germinated within the first 3 days of incubation, and practically all germinated within 10 days. Freshly matured seed, however, germinated very slowly, few if any sprouts appearing for the first 10 days. Very little germination could be induced in the first 60 or 90 days, and germination was not completed in most cases for 200 days or more. The tendency

of seeds to mold or rot when kept in a moist incubator for a long period undoubtedly explains the relatively low total germination of some of the samples. The burs picked before shattering apparently show a more rapid rate of germination than the freshly matured burs, though not necessarily a higher total.

These tests indicate that puncture vine enters a period of rest or dormancy upon reaching maturity, even under conditions of temperature and moisture most favorable for germination. They further indicate the unreliability of short-time germination tests on seed of the current year's crop, and the need for caution in interpreting results of treatments of newly matured burs.

That greenhouse tests are even less reliable than incubator tests may be seen from table 3. Samples of both treated and untreated burs were tested in duplicate, one lot in soil in the greenhouse, the other in blotters in the incubator. The greenhouse-tested lots were generally lower in germination than the incubator-tested lots. In several of the incubator tests a number of the burs which remained ungerminated were still undecayed at the termination of the test, and possibly contained viable seed. Goss[12] has recently described an improved method of germination in which sterile soil is used in the incubator instead of cloth or blotters. Although comparative tests are not reported, the new method is expected to prove more reliable than the blotter method.

To obtain a reasonably accurate germination test of the current season's burs, one must hold the sample for a period of at least 6 months before testing. Approximately the same result may be obtained by incubating for a like period, but this method is less reliable because of the probability of losing some of the seeds by mold or decay. A quicker way of approximating viability is to soak the sample in water until the burs soften, when they can be cut into without difficulty, and one can readily see from a cross section which seeds are normal in size and which are shriveled. The appearance of the seed is a fairly reliable indication of viability. For example, a laboratory germination test of a certain lot of burs showed sprouts in 35 out of 49 burs, or 72 per cent. Out of 25 burs from the same lot which were cut open and examined, 20, or 80 per cent, contained apparently viable seeds; the difference is well within the probable error for such small samples. Another sample showed apparently viable seed in 97 out of 100 burs dissected, while 86 per cent of a duplicate sample germinated when incubated in the laboratory.

Viability of seeds in burs treated with Diesel oil may readily be detected in this manner, as the penetration of the oil into the bur

can easily be followed. When burs are treated with colorless chemicals, however, inspection does not immediately show whether or not the germinability of a seed has been affected.

The dormant or resting state of newly matured seed undoubtedly protects the plant against the late rains which might cause seeds to sprout too late for the plants to mature before frost. The nature of the protection thus afforded to the seed is not known, but is probably associated with moisture absorption. The change, whatever it may be, is apparently not completed until the burs shatter from the plant.

TABLE 3

Comparison of Greenhouse Tests with Incubator Tests for Germination of Puncture-Vine Burs

(Greenhouse tests continued 55 days, incubator tests 61 days.)

Sample No.	Greenhouse test, per cent germinated	Incubator test	
		Per cent germinated	Ungerminated* seeds, per cent undecayed
1	4	7	40
2	4	22	0
3	14	3	0
4	6	11	49
5	14	2	75
6	0	7	31
7	7	6	0
8	8	6	8
9	16	14	0
10	0	5	23
11	0	1	5
12	18	23	13
13	8	17	0

* In some of the incubator tests in this series a number of burs which remained ungerminated at the end of the 61-day period were still undecayed and possibly contained viable seed.

Burs which are picked from the plant when still green, even if fully developed, will germinate more quickly than ripened burs of the current season's growth, although the total germination may be less. When the resting period is interrupted by picking the burs or killing the plant before the dormant stage is reached, the rate of germination is apparently accelerated. The length of this resting period has not been determined. The newly matured burs tested in the laboratory did not reach 50 per cent of their total germination until they had been in the incubator about 90 days; old, mature burs, on the other hand, completed about 90 per cent of their total germination in the first 3 days. Burs picked when still green reached 50 per cent of their total germination in 10 to 20 days.

CONTROL OF PUNCTURE VINE

The fact that early attempts to control puncture vine were largely a failure is easily understood. The only method offered before 1922 was that suggested for annual weeds in general: cultivating or cutting to prevent the formation of seed, and burning plants that may already have formed seed.[23] As puncture vine sprouts irregularly throughout the season and produces seed at an early stage of growth, one must go over an area repeatedly at frequent intervals in order to make progress in control by cultivation. Although this method is satisfactory on cultivated land in the hands of a careful operator, puncture vine on roadsides and other uncultivated land affords a continual source of reinfestation if not controlled.

Natural Enemies.—Small rodents are fond of puncture-vine seeds and will gnaw into the burs to get at them (fig. 5*D*). Rabbits readily devour the young shoots and sometimes eat off the runners down to the crown. Turkeys are said to be especially fond of the crowns of puncture-vine plants. Several species of aphis occasionally attack puncture vine, sometimes severely injuring it, and dodder is sometimes found growing upon it; otherwise, this weed in California seems unusually free from attack by insects, diseases, and parasites.

Treatment of Infested Products.—The removal of puncture vine from grain and seed crops, wool, and other products which normally go through a cleaning process, presents no unusual difficulty; but the disposal of bulky products such as hay, straw, manure, and screenings, when infested with puncture vine or other noxious weed seeds, presents a problem of some magnitude unless the material can be utilized on the premises where it was produced. Infested material is not welcome in territory where an effort is being made to keep these weeds under control. Since such products are for the most part of small value, any process that will add materially to their cost without correspondingly increasing their value must be considered impracticable.

With the ordinary milling process used in the manufacture of alfalfa meal, the smaller puncture-vine burs work their way through the screens into the finished product. When passed through mesh not larger than $\frac{1}{32}$ inch, however, the meal is pulverized finely enough to destroy the seed of puncture vine. A process whereby the meal is ground to nearly the consistency of flour and bolted through fine-mesh screens has afforded an outlet for a considerable quantity of infested hay which otherwise could be disposed of only locally. It

is impossible to find any puncture-vine burs in this product, or to germinate any seed from it.

Although the greater part of the straw, chaff, and other organic refuse containing weed seeds is now waste, and can be destroyed without loss if necessary to prevent the spread of weed seeds, a considerable amount is used as manure in the orchards of southern California. The general practice in recent years is towards less cultivation in the orchards; and the introduction of weed-infested manure and straw, without the intensive cultivation necessary for weed control, is liable to result in the establishment in the orchard of puncture vine and other weeds difficult of eradication.

The composting or fermentation of manure has long been known to destroy weed seeds. Pammel(32) in Iowa found that seeds of most weeds were destroyed after one month of composting; in 5 weeks only a very small percentage of any seed germinated; and in 60 days, of 52 kinds of seed tested, all were destroyed. Fruwirth(10) in Germany found that a small number of seeds germinated after ''cold'' fermentation of the ordinary yard manure, but none survived after ''hot'' fermentation (60° to 80° C).

The destruction of the viability of weed seeds by the composting of manure suggests the use of a similar process for straw and other bulky organic material. Waksman, Tenney, and Diehm(43) in New Jersey found that decomposition of such material in the composting process results largely from breaking down of the cellulose and similar components of plant tissues by microorganisms. These microorganisms require large quantities of available nitrogen and phosphorus, both of which are present in sufficient quantities in manure; but in straw and similar material, nitrogen is low and must be added.

To determine the effect of decomposition, accelerated by the liberation of ammonia, on the germination of puncture vine contained in organic refuse, two sample of cleanings were taken after the conclusion of Neville's(30) puncture-vine feeding experiments at the Los Angeles Union Stockyard previously noted, and removed to Pomona on May 23, 1928. Stack No. 1, composed of 3,500 lbs. of cleanings from the feed boxes, consisting largely of straw and burs, was treated with 200 lbs. of ammonium sulfate and 200 lbs. of ground limestone. Stack No. 2, composed of 7,200 lbs. of cleanings from the corrals, consisting largely of manure and burs, was treated with 300 lbs. of ammonium sulfate and 300 lbs. of ground limestone. The stacks were laid down in alternate layers of cleanings, sulfate of ammonia, more cleanings, and ground limestone, with flat tops to facilitate

watering. Each stack was covered with approximately 1,000 lbs. of barley straw and watered at frequent intervals throughout the experiment. In 3 months stack No. 1 had settled to approximately one-fourth its original volume, and stack No. 2 to approximately one-third. In 6 months the interiors of the stacks were examined and found to have become thoroughly decomposed. No puncture-vine burs were recognizable, nor could any sprouts be germinated from the samples. No analysis was made of the product. It resembled good barnyard manure, was odorless, and crumbled readily. The sample from stack No. 1 was grayish in color; that from stack No. 2, yellowish. When the stacks were torn down 14 months after the treatment the outer layers, no doubt because they could not be kept wet during the process, had not yet decomposed, and contained an abundance of puncture-vine burs which germinated readily.

Mechanical Control.—Any means of destroying the entire plant is sufficient to control puncture vine, provided only that it be applied before the seed is formed, and repeated whenever new plants appear.

Cultivation by any of the ordinary tillage implements when the plants are in the seedling stage is the easiest and quickest way to control the pest. The more rapidly the seeds can be made to germinate, the sooner will the supply be exhausted from the soil. Frequent irrigation during the warmest part of the season will hasten germination; plowing or deep cultivation will retard it.

Hand pulling or hoeing may be used to control small patches or to supplement cultivation in spots not reached by the tillage implement. If no burs have formed, the plants may safely be left on the ground. If only immature burs incapable of shattering are present, the plants should be carefully gathered and burned, as some of these burs will probably contain viable seeds. If, as is most often the case, any of the burs have shattered or are sufficiently mature to shatter when lifted, the plants must be treated in place with chemicals or the burs carefully picked up by hand, if the infestation is to be eliminated.

Scraping with a road grader is an inexpensive means of destroying numbers of young plants on the roadside, but only serves to spread the burs if done after seed is formed (fig. 9). To be of value in the control of puncture vine, scraping must always be supplemented by other work.

The management of various crops so as to keep puncture vine under control is sometimes a serious problem. Such crops as late potatoes, melons, and beans, as well as some varieties of grapes, cannot be worked during the latter part of the summer; and unless

hand work is resorted to, puncture vine will continue to sprout and grow to maturity from seeds remaining in the soil, as long as sufficient heat and moisture are present. Alfalfa also presents a difficult problem. In a good stand of young alfalfa in vigorous condition, cut at the proper stage, puncture vine does not mature seed; but if hay free from puncture-vine burs is to be produced on infested soil, special attention must be given to control on the borders and in spots where the stand is thin.

Fig. 9.—Puncture vine on roadside, Kern County.

Heat.—Burning is, of course, adequate as a control measure if both plants and burs are destroyed. However, it requires a great amount of heat to consume green plants, and this method is impracticable on a large scale. To determine the effect of heat on germination of puncture vine, heavily matted vines were treated with 50 per cent oil emulsion. The dead plants were fired when dry, but they were not completely consumed. A sample taken after treatment with oil but before firing gave a germination test[4] of 7 per cent, as against 52 per cent in an untreated check sample. A sample taken after firing tested 12 per cent. The apparent increase, though within the probable error for such tests, may have been caused by an interruption of the resting period, which increased the rate of germination (see page 18). In another series of tests, the flames were fed with fuel oil until the plants were entirely consumed, and although many burs remained, no germination could be induced. It apparently made no difference whether the plants were first killed with oil and resprayed before burning or whether the burning was done immediately after treat-

[4] Records of all germination tests reported herein are on file in the State-Federal Seed Laboratory at Sacramento.

ment. When the previous treatment completely destroys the viability of the seeds, as is usually the case where Diesel oil is used, no additional benefit is, of course, derived from the burning other than the removal of dead vegetation.

No germination was reported in tests of burs treated with heat from a weed torch nor in burs treated by live steam from a railroad engine.

Qualities of Chemicals Required for Control.—A herbicide, to be satisfactory for the control of puncture vine under all conditions, must be cheap, readily available, easy to apply, and harmless to the soil and to animals, and must be capable of killing not only the plant, but also the seed. Certain petroleum products, particularly Diesel oil, more nearly meet all of these requirements than any other chemicals tested. Sulfuric acid, arsenicals, and chlorates, however, have all been successfully used for puncture vine under special circumstances. A great many other compounds are also useful as weed killers, among which may be mentioned copper sulfate, copper nitrate, iron sulfate, ammonium sulfate, sodium bisulfate, sodium chloride, sodium carbonate, sodium hydroxide, sodium bichromate, hydrochloric acid, nitric acid, carbolic acid, and formaldehyde. Any of these chemicals will readily kill young puncture-vine plants; but only certain petroleum derivatives are known to kill the seeds as well.

Quantities of Chemicals Required.—The quantity of a chemical solution required to treat a given area varies so greatly with the density of foliage, the chemical used, the style of equipment, the manner of application, and the efficiency of the operators, that it is difficult to estimate except by experience. Thorough coverage is more important with oil, which is applied to kill the seeds in all states of maturity, than with chemicals which are applied to kill the plants only. On the other hand, because of its spreading qualities, less oil is required to obtain thorough coverage than is possible with water solutions. Pipal[36] in Indiana applied oil to wild garlic at the rate of 75 gallons per acre. For various water solutions on morning-glory and other weeds, 100 to 400 gallons per acre is recommended by workers at several different experiment stations. Brown and Streets[6] in Arizona recommend 200 gallons of sulfuric acid solution per acre for puncture vine. Gray[13] noted that about 300 gallons of an arsenical spray solution per acre is required for the treatment of wild morning-glory. In field practice 1,000 gallons of spray solution per acre is sometimes required to cover dense vegetation.

Equipment for Application of Chemicals.—Since chemical control measures have been extensively employed, a great variety of equip-

ment has been utilized for the spraying of puncture vine and other weeds. The designing of special equipment for weed spraying is somewhat complicated by the requirement that it be adapted for handling various chemicals, including oil, strong acids and corrosives, and powerful oxidizing agents, for which the usual type of orchard spraying equipment is not fitted.

One of the first rigs designed exclusively for weed spraying employed a rotary gear pump. Pumps of this type will deliver a large volume of material with a small amount of power; they are inexpensive, and reasonably durable, provided the spray material is well screened against grit and sand. A 1-inch rotary gear pump may be

Fig. 10.—Weed sprayer with compressed air atomization and multiple nozzle. (From Ext. Cir. 54.)

operated at a pressure of 75 to 100 pounds. High pressure appears to be of less importance than volume of material in the spraying of weeds, especially puncture vine. A number of such rigs have been used in various parts of the state.

Another rig designed especially for weed spraying utilized the principle of atomization with compressed air instead of a pressure pump (fig. 10). This type of rig, though also incapable of high pressures, is adaptable to various problems encountered in weed spraying. By regulating the proportions of fluid and air, one can obtain a spray of almost any degree of fineness. This type of sprayer also makes an excellent weed burner, utilizing atomized oil for fuel.

The most common type of orchard sprayer employs a plunger pump, developing relatively high pressures of 200 to 400 pounds,

the capacity depending upon size and style. Such a sprayer may be readily adapted for weed spraying.

In hand equipment the types used for garden spraying have been used also for weed spraying. The compressed-air knapsack sprayer is generally favored over the displacement type. A hand pump with a trombone-like action, equipped with a knapsack tank, has been used for spot spraying of puncture vine.

If acids or corrosive chemicals are used, a wood-stave tank is preferable to a metal one. So-called "porcelain-lined" cylinders should be replaced with brass, bronze, or solid porcelain. If oil is used, a metal tank is better, but wood stave may be used if care is taken to fill it with water occasionally to prevent shrinking. Rubber parts should be replaced with fiber where possible. A specially treated gasoline hose now obtainable withstands Diesel oil much better than the ordinary spray hose.

Application should be made with a spray rod. A spray gun is excellent for tall dense growth, but not for prostrate weeds like puncture vine.

The type of nozzle varies with the kind of weeds to be sprayed. A nozzle delivering a cone-shaped spray is satisfactory if so constructed as to give a uniform mist throughout the cone; but with a nozzle which delivers most of the material at the periphery, uniform coverage cannot easily be obtained. A fan-shaped spray is usually preferred for spraying strips of weeds, and a cone-shaped spray for spot spraying. Several nozzles are sometimes used on a single rod (fig. 10) or on a boom attached to the rig.

Sulfuric Acid.—A 2 per cent solution of sulfuric acid is recommended by Brown and Streets[6] in Arizona for the control of puncture vine. In this dilution it is probably the cheapest material available for the purpose. The same investigators found that dilutions of 2 to 10 per cent can be used effectively on a large variety of weeds. Åslander[2] observed that sulfuric acid is more effective in a dry atmosphere and at higher temperatures. Because it does not affect the germination of the seeds, it is effective only for use on young plants. Although not injurious to the soil and nonpoisonous to animal life, it is very disagreeable to use as a spray, for it will eat the clothing and burn the flesh; but with reasonable precautions it can be handled safely. In dilute solutions it is highly corrosive to metal. The standard types of spray rigs are quickly damaged by its use. No satisfactory equipment for large-scale spraying of sulfuric acid has yet been developed.

Gray[13] found that acid sludge (a by-product from oil refineries, containing about 50 per cent sulfuric acid) gave encouraging results on morning-glory, and believed the action to be due partly to the highly toxic constituents of petroleum distillates removed by the sulfuric acid in the refining process. That these constituents, if present, are combined with the sulfuric acid rather than with the tarry residue obtained upon hydrolyzing the acid sludge is indicated by tests made in the San Fernando Valley in 1927 with acid sludge in which the acid was removed or neutralized. Neither a 10 nor a 20 per cent solution of the neutralized acid sludge had any apparent effect on puncture-vine plants.

Crude acid sludge in concentrations of 2½, 5, 10, and 20 per cent was applied to puncture vine in the Imperial Valley in 1925. At the 2½ per cent concentration the plants were wilted; at 5 per cent they were killed within 24 hours. The treatment did not affect the viability of the seeds. The treated burs in every case showed a higher germination than the untreated check sample, possibly because of an interruption of the resting period.

Arsenic.—A number of compounds of arsenic are effective weed killers. Aside from numerous proprietary preparations, the compounds most commonly used are sodium arsenite and arsenic acid, both obtainable in either liquid or solid form. Arsenic acid has been used in Queensland in the destruction of prickly pear, White-Haney[45] reporting it to be the most effective specific for the purpose. Johnson[21] found it more effective than other arsenic compounds on Russian knapweed and other deep-rooted perennials. Sodium arsenite is somewhat cheaper than arsenic acid and equally effective for annuals like puncture vine. All arsenic compounds, being poisonous to animals, cannot safely be used to spray vegetation to which grazing animals have access. Sodium arsenite is said to be particularly attractive to livestock. Soluble compounds of arsenic may be absorbed through the skin. A solution or paste of lead acetate, ferric hydroxide, or other antidote should be kept on hand when arsenic is being used. Vegetation burns somewhat less readily when sprayed with arsenic. A poisonous gas, arsine, having the odor of garlic, is given off when weeds sprayed with arsenic are burned.

Soluble arsenic compounds readily kill the plants, but not the seeds, of puncture vine. A large number of samples of burs treated with arsenic, mostly in the form of proprietary preparations, have been sent to the Seed Laboratory for germination tests.[19] While some of the tests showed a very low germination, the results were by no means uniform, ranging from 0 to 73 per cent. In general, the

tests on green burs ran lower than those on mature burs; but since many of these tests were continued for less than 4 months, the results cannot be said to be conclusive (see page 18). Perhaps arsenic, when applied to the plant, may be carried into the green seed pods to a sufficient extent to affect germination. That translocation of arsenic takes place in plants has been demonstrated in the wild morning-glory (*Convolvulus arvensis*) by Kennedy and Crafts,[26] and in the prickly pear (*Opuntia inermis*) by White-Haney.[44] The variable results with arsenic might be explained by variations in the condition of the plants at the time of spraying, the degree of maturity of the burs possibly affecting the movement of the poison into the seeds.

The effect of arsenic on the soil has received the attention of a number of investigators. McGeorge[28] in Hawaii, with an average rainfall of 200 inches, found no arsenic below the surface 4 inches of soil to which sodium arsenite had been applied as a spray annually for 5 years at the rate of 3 applications per year, 5 pounds of arsenic (As_2O_3) per acre being used for each application. He concluded that ''soils possess strong fixing power for arsenic, and that when a sodium arsenite spray is used for destroying weeds, the arsenic will ultimately be deposited in the surface soil, there to remain in spite of the leaching effect of rains or irrigation.'' Åslander[3] also found that arsenic penetrates the soil but slowly. He permitted a N/10 solution of sodium arsenite to leach through a 15-cm core of soil. In one type of soil having a reaction of pH 5.77, arsenic was found in a concentration of only N/1,000 after 34 days, increasing to about N/500 10 days later. In another soil having a reaction of pH 7.87, a trace of arsenic was found after 18 days, increasing to N/400 in 30 days. On the other hand, Schulz and Thompson,[38] working in the north central states, found that the leaching of arsenic from surface soil was very rapid and extensive, although they did not show to what depth the arsenic penetrated the soil. Variations in soil composition were shown by each of these workers to influence the amount of arsenic retained. Greaves and Carter[15] found that sodium arsenite was ''less toxic to ammonifiers and nitrifiers in a loam soil than in a sand, and still less toxic in an organic loam than in a silt loam,'' probably in part because of a combination of the arsenic with the organic colloids in the soil.

Where weeds have been sprayed with arsenic acid, subsequent vegetative growth is more vigorous than on unsprayed areas. It is well known that plants are stimulated by small quantities of arsenic, whereas larger amounts are toxic. Schulz and Thompson,[38] inves-

tigating the relative toxicity of arsenious acid, sodium acid arsenite, orthosodium arsenite, and sodium arsenate, found a decrease in toxicity in the order named. Greaves and Carter[15] found that the total number of microorganisms in soil was greatly increased by the application of arsenic; but that "although comparatively large quantities of arsenates (salts of arsenic acid) may accumulate in a soil without injuring its beneficial microflora, only small quantities of sodium arsenite may accumulate without producing ill effects."

Gray,[13] working at Centerville, California, found that all of the plots "to which an ounce or more of arsenic trioxide (as sodium arsenite) had been applied per square yard were barren of all vegetation, except morning-glory, for 14 months, notwithstanding the leaching by the rains of two winters," and suggested the use of this material to sterilize fence rows and roadways.[14]

Schulz and Thompson[38] found that the presence of arsenic in the soil did not prevent the germination of seeds of various kinds but interfered with root development, so that the seedlings, other than rye, died after attaining a height of 2 or 3 inches.

Chlorates.—Puncture-vine plants are readily killed by chlorate solutions in concentrations of 2 per cent or more, but Ball[4] has shown that chlorates do not kill the seeds (fig. 11). In several series of tests, the treated burs actually showed an increased percentage of germination, possibly because of interruption of the resting period.

Chlorates have a detrimental effect on the soil[46] and are therefore not suitable for use in agricultural land, although the injury probably does not last more than a year or two unless excessive amounts are used, since chlorates are relatively unstable compounds and tend to break down into the less toxic chlorides. In a number of instances, injury to fruit trees followed the application of chlorates to weeds in the orchard. Åslander[3] found that chlorates penetrate the soil freely and decompose but slowly. It required 10 weeks for sodium chlorate to decompose in soil kept at 30° C (86° F), and decomposition proceeded much more slowly at lower temperatures. This fact undoubtedly explains the temporary sterilization of soil treated with chlorates. The number of puncture-vine plants recurring the same season is less after treatment with chlorate than where other methods of treatment are used. For the purpose of soil sterilization, however, chlorates are more costly and less permanent than sodium arsenite.

Chlorates are relatively harmless to animals, except in excessive quantities.

When intimately mixed with dry organic matter, chlorates are highly combustible; and when they are used as weed killers, the

sprayed herbage presents an unusual fire hazard. This fact is of no great importance in the control of puncture vine because of its prostrate habit, unless the growth of the weed is exceptionally heavy or unless it is in proximity to dense, dry vegetation. Certain precautions should, however, be taken in the handling of chlorates. The clothing and shoes of workers should be fireproofed and waterproofed, and the wood parts of the spray rig kept wet and washed frequently; for, under conditions of low humidity, chlorate-saturated clothing or wood may become ignited even by friction.

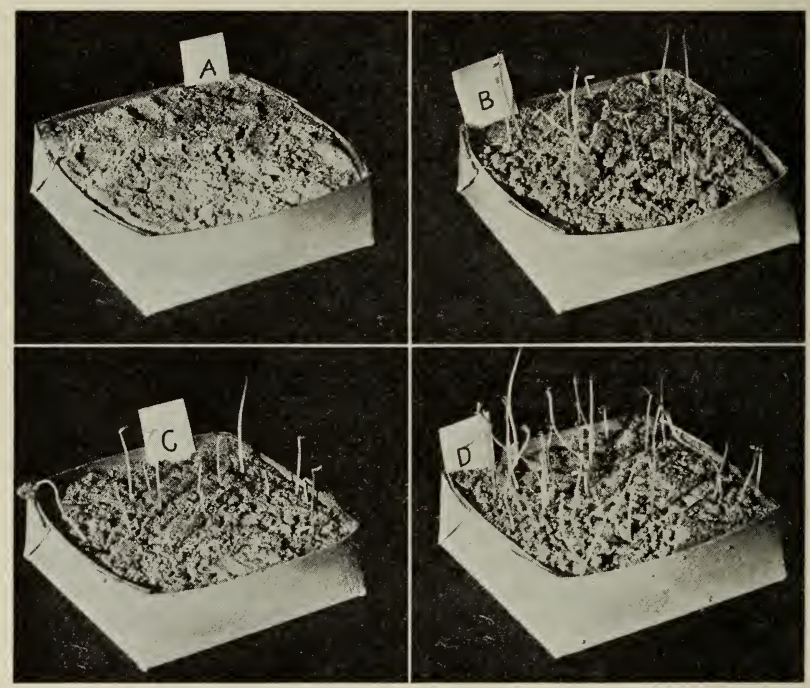

Fig. 11.—Comparative effect of oil and chlorates on the germination of puncture vine. *A*, treated with oil—no germination; *B*, treated with chlorate, ½ lb. per gallon—40 per cent germination in 8 days; *C*, treated with chlorate, 1 lb. per gallon—33 per cent germination in 8 days; *D*, untreated—73 per cent germination in 8 days.

Sodium chlorate is the only chlorate compound extensively used as a weed killer. Chlorates of ammonium, barium, calcium, magnesium, potassium, and zinc, though effective, are more costly. One proprietary preparation contains a mixture of sodium chlorate with calcium chloride, the latter, which is deliquescent, being added for the purpose of reducing the fire hazard. Willard[46] in Ohio found the mixture "at least as effective as sodium chlorate in proportion

to its chlorate content, but not equal to sodium chlorate pound for pound.'' Offord and d'Urbal[31] have shown that the addition of calcium chloride definitely decreases the toxicity of sodium chlorate. The extent to which the fire hazard is actually reduced by the presence of calcium chloride has not been satisfactorily demonstrated. Theoretically, the calcium chloride would draw enough moisture at normal humidity to prevent sprayed herbage from becoming readily ignited; but in the dry atmosphere which may occur in most sections of California at any season, experience has proved that the fire hazard cannot be minimized, and that organic materials saturated with chlorate ignite very readily in spite of the presence of calcium chloride.

Diesel Oil and Other Petroleum Products.—Various petroleum products have been tested as weed killers from time to time. Jones and Orton[24] in Vermont, in 1899, reported unfavorably on the use of kerosene as compared with other chemicals as a herbicide. Thompson and Robbins[42] in Wisconsin, however, found kerosene as effective as gas oil and more effective than either fuel oil or gasoline for killing barberries, although the action was very slow, and complete killing was not noted in some instances for nearly a year after treatment. Arthur[1] in 1913 commented on the effectiveness of orchard heating oil as a weed exterminator; Pipal[36] in the following year recommended it for the control of wild garlic in Indiana; and Talbot[41] reports that waste crankcase oil thinned with kerosene is effective for the same purpose. Gray[13] in California reported, after testing a number of petroleum distillates on miscellaneous weeds: ''The cheaper distillates were more effective than refined distillates such as kerosene and similar products. Petroleum products containing a large percentage of aromatic and cracked oils were more effective than those containing a lesser percentage.''

Horticultural Commissioners Call, Stroup, and Rutherford in 1922 made tests of petroleum oils on puncture vine, each reporting a marked reduction the following year in the infestations treated. Bourcart[5] attributes the temporary sterilization of the soil by petroleum to the generation of petroleum vapors, and comments on the production of a more intense vegetation after the evaporation of the petroleum, a result repeatedly observed in California. Pipal[36] found that orchard heating oil, even when thoroughly mixed with the soil, had no appreciable effect on the germination of wheat and corn planted immediately after treatment, although it reduced the germination of garlic bulblets; whereas crude petroleum applied in the same manner had a marked injurious effect on germination of the grain.

A large number of different types of petroleum oil, including both commercial grades and special distillates, have been tested as to their effects on puncture vine and other weeds. Practically all those tested killed the tops of the plants. Some types failed to penetrate the crowns, however, so that new growth appeared after treatment. A considerable variation was noted in the effects on seed germination. Diesel oil in general was found most satisfactory. Of 29 laboratory germination tests of puncture-vine burs treated with Diesel oil in various parts of the state, 15 showed no germination; 3 showed 1 per cent; 6, 2 per cent; 3, 3 per cent; 1, 4 per cent; and 1, 6 per cent. Two lots of crude oil showed 0 and 1 per cent respectively, and waste cylinder oil, 1 per cent. Various types of fuel oil showed 0, 9, 33, 49, and 83 per cent germination, respectively; and distillates showed almost as much variation, individual samples ranging from 0 to 49 per cent germination.[5]

By reason of its superiority in destroying the viability of seeds, Diesel oil and similar grades known as orchard heating oil, smudge oil, gas oil, tops, and slop distillate, have been extensively used in California for the control of puncture vine. Diesel oil is a commercial grade of petroleum of great variability. It is readily available in quantity at a low cost. It is stored in bulk at various distributing centers, chiefly in the larger cities and at maritime points, its principal use being for fuel in marine and industrial engines. In the fruit-growing sections, a large amount is stored for orchard-heating purposes. The principal item in the cost of oil is freight; hence the price is necessarily determined by the distance from the refinery. Where the cost of Diesel oil is too great, waste crank case oil or crude oil may be used, if thinned with distillate to a consistency which will permit its being sprayed. The more highly refined oils and distillates are not recommended, for they cannot be depended upon to destroy the viability of the seeds.

Used as a spray, Diesel oil is a cheap and effective herbicide, not only for puncture vine, but for all types of annuals; for grasses, which, because of their concealed growing points, are not affected by many chemicals; for noncreeping perennials such as artichoke and other thistles; and for destroying the viability of seeds. It is especially valuable for destroying vegetation in ditches, fencerows, firebreaks, roadsides, or similar locations. It also aids in burning dead vegetation.

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[5] Records of all germination tests reported herein are on file in the State-Federal Seed Laboratory, Sacramento, California.

In spraying puncture vine with oil, unless the application is thorough, some of the burs may not receive enough oil to destroy the seeds. The green burs before shattering apparently do not absorb oil so readily as the dry burs, probably because of the moisture content. Furthermore, the seeds are borne towards the center of the bur cluster, where they are protected by the woody portion of the bur (fig. 6), and unless a sufficient quantity of oil is applied to penetrate to the seed cavities, some of the seeds may not be killed. For this reason a second application is sometimes recommended; for the oil penetrates the seed cavities more readily after the green burs have dried and shriveled, exposing the thinner side walls of the burs (fig. 5*E*). In this connection, the importance of thorough application in the first treatment is apparent. Where a satisfactory grade of oil is used, and the application is thorough, the kill is satisfactory, and little, apparently, is to be gained from a second application; but in the case of heavily matted vines, or vines growing in dense vegetation, thorough coverage is difficult, and in this case a second treatment is advisable as an additional safeguard. The effect of burning after treatment with oil has already been discussed (page 23).

Oil Emulsions.—In order further to reduce the cost of oil as a spray for weeds, attempts were made to emulsify it with water, according to the formula for crude oil emulsion as sometimes applied to dormant deciduous fruit trees. The first Diesel oil emulsions for weed spraying were prepared in 1925 by Whit C. Barber, Kern County Horticultural Commissioner. One emulsion was prepared with 50 per cent each of oil and water, and one with a mixture of 25 per cent oil and 75 per cent water. In each case 2 pounds of caustic soda per 150 gallons was added, and the mixture agitated in a power sprayer. The 50 per cent emulsion was fairly stable; the 25 per cent separated somewhat after standing for some time. Both mixtures were effective in killing the plants. The 50 per cent emulsions gave a fairly satisfactory kill on the seeds, the treated sample testing 7 per cent germination as against 87 per cent for the untreated check sample. The 25 per cent mixture reduced the germination to 47 per cent.

When emulsions of many different grades of oil were attempted, the results were not always so satisfactory. The desirable type of emulsion for weed killing is the water-in-oil type,[20] in which the oil is in the external phase and comes first into contact with the plant tissues.

The invert, or water-in-oil, type of emulsion, with Diesel oil, is chocolate brown or black in color, and tends to spread on an oiled

surface and to collect in drops on a water surface. The obvert, or oil-in-water, type is whitish in color, spreading on a water surface and collecting on an oiled surface.

A considerable variation in emulsifiability of different lots of Diesel oil was experienced, regardless of the emulsifier used. The consistency of the 50 per cent emulsion was nearly always satisfactory, but the 25 per cent sometimes refused to emulsify with the oil in the external phase; at other times the emulsion became too heavy to spray and had to be thinned by the addition of more oil. These difficulties with the 25 per cent emulsions, it was found, could be mitigated in a number of ways, such as by reducing the quantity of emulsifier used, adding other substances, reducing the speed of the agitator, or stopping agitation entirely after the emulsion was made; but the 25 per cent mixture was generally unsatisfactory for inexperienced operators.

It was soon discovered that certain lots of Diesel oil would emulsify with the oil in the external phase without the addition of any substance as emulsifier, and that the same difficulty with thickening or failure to emulsify was experienced with certain lots of oil whether or not an emulsifier was used. Analysis of samples of known behavior showed that the only variable factor which might account for the differences in emulsifiability was the asphalt content. The limits of satisfactory asphalt content, expressed as asphalt by evaporation, appear to be from 2 to 5 per cent.[22] Diesel oil is readily obtainable within this range.

If the asphalt content of an otherwise satisfactory product is too low, as evidenced by failure to emulsify with the oil in the external phase, it can be raised by the addition of crude oil or hot road oil. If it is too high, so that the emulsion tends to become too thick to spray, the remedy is to use the oil in greater proportion, or to dilute it with an asphalt-free distillate, or to use it unemulsified.

Various petroleum products and distillates in emulsion with water were tried, and germination tests were made of a number of samples taken from plots treated in the field with oil emulsions of both types. In some cases a complete kill was obtained, but not so universally as where oil was used full strength. Thoroughness of application undoubtedly has an important bearing on the results of the germination tests; for the amount of oil actually applied to the surface of the plant tissues is reduced when emulsions are used. In some cases the treated sample showed as much as two-thirds as many viable burs as the untreated sample; but in most cases the viability of the treated samples was less than 5 per cent. Where Diesel oil emulsion was

used with the oil in the external phase, the results were practically the same as where Diesel oil alone was used: approximately one-half of the samples showed no germination, and none showed more than 10 per cent.

Little study has been given to the chemistry of Diesel oil. Being a residual product, it is extremely variable. In an attempt to determine what constituents of petroleum are of the greatest value for weed control, a number of petroleum products were applied in water emulsions to puncture vine in 1927. These products included fractions high in phenolic bodies and in organic acids, heavy and light fuel oils, residues or extracts from the Dubbs and Edeleanu processes, and tar or sludge with the acid removed or neutralized.

Of these various materials, only three, the residuum from the Dubbs process and two extracts from the Edeleanu process, were effective in killing the plants completely. Each of these products, as well as other of the more effective petroleum products, such as Diesel oil and waste crank-case oil, contains relatively large proportions of either aromatics (C_nH_{2n-6}) or olefins (C_nH_{2n}), thus tending to confirm Gray's observations[13] previously noted (page 31). The products containing phenolic bodies and organic acids in high proportions killed the stems, but not the crowns of the plants; for new shoots started out after the treatment. None of the products in this test completely destroyed the viability of the seed. The fact that all were applied in emulsion, with a relatively large proportion of water and with the water in the external phase, may account for the failure to obtain a more complete kill. Diesel oil in 50 per cent emulsion with the oil in the external phase, applied as a check, gave a complete kill of the seeds as well as the plants. Probably some of the products tested, or other similar products, or a combination of them, when used undiluted, or combined with an oil having a sufficient asphalt content to form an emulsion with oil in the external phase, would give as good results as Diesel oil, or better; but unless such a product could be made available in sufficient quantity and at a low enough cost, it is not likely to replace Diesel oil as a weed killer.

Soil Sterilization.—The possibility of soil sterilization to prevent the recurrence of puncture vine in areas where much seed is present in the soil has received some consideration. The most pressing problem in puncture-vine control is its elimination from roadsides and similar areas from which it is chiefly spread, and in such situations there is no objection to permanent sterilization of the soil.

A plot at Visalia infested with puncture vine was treated in 1927 by Frank R. Brann, Tulare County Horticultural Commissioner,

with a proprietary preparation consisting principally of sodium arsenite. This plot to date (1931) is reported as still barren of puncture vine, even when irrigated, whereas a check plot continues to sprout the weed each season, although none has been permitted to form seed for more than eight years.

An attempt to apply the sterilizing solution on a larger scale in Tulare County in November, 1928, was less successful, however, and had very poor results. The effects of arsenic and of chlorate compounds on the soil have already been discussed (pages 28 to 29). Sodium chloride, sodium hydroxide, calcium chloride, and many other salts, as well as crude oil[36] also inhibit the growth of weeds, but the excessive amount required to sterilize the soil makes their use for this purpose prohibitively expensive.

A series of puncture-vine plots was treated in Orange County in May, 1930, with sodium arsenite, sodium chlorate, and Diesel oil. These plots were repeatedly disturbed by the road grader during the 1930 season, so that no check could be kept of the number of puncture-vine plants which appeared; but none were found in any of the plots except the untreated check plot. In 1931, up to July 15, but 6 puncture-vine plants appeared in the sodium arsenite plot, 55 in the sodium chlorate plot, 52 in the oil plot, and 41 in the untreated check plot.

A further series of 16 soil-sterilization plots, each of 1 square yard, was laid out, and twelve different chemical solutions were applied. Milo seed was sown before the chemicals were applied, and its germination was used as an index of the degree of soil sterilization. There was no germination in the plots treated respectively with arsenious acid, sodium arsenite, sodium chlorate, and a proprietary preparation containing copper salts. Check plots were thickly covered with milo seedlings. The more promising treatments were therefore repeated, first in square-yard plots and later in 100-square-yard plots containing miscellaneous weeds.

In the arsenic plots in which the arsenic was in excess of 1 ounce of As_2O_3 per square yard, a few seedlings appeared, but soon died. In the chlorate plots, the weeds sprouted freely, but had a yellowish unhealthy color, and eventually died in all plots containing in excess of 4 ounces of sodium chlorate per square yard.

In May, 1931, arsenic as sodium arsenite was applied to several miles of roadside in Orange County. To date (April, 1932), no annual weeds have appeared where the soil has remained undisturbed, with the exception of a small amount of water grass (*Echinochloa crus-galli*). The following soil types were included in the area treated: Chino clay

loam, Chino silty clay loam, Chino silty clay (heavy phase), Hanford sand, Hanford fine sandy loam, Ramona loam, and peat.

The permanence of the treatment is yet to be determined; but the results to date justify the belief that much greater progress can be made in the control of puncture vine by a more extensive use of soil sterilization.

SUMMARY

Puncture vine has been known in California since 1903, and probably was introduced some years earlier. It appeared first along the railroads, but spread rapidly in the state along with the increase of automobile travel. Although tires have been the principal means of dissemination, it is also carried by animals, by various crops and products, and by almost any object with which it comes in contact.

The longevity of puncture-vine seed is not known. A plot on which no seed has matured for the past eight years has continued to sprout seed each season in undiminished quantities.

The seasonal growth appears to be correlated with soil moisture and temperature. Under nonirrigated conditions, 90 per cent of the total number of plants for each season sprouted by July 15 on one plot observed. The total number of plants sprouted was highest in those seasons when the May and June temperatures were highest, those being the only months of sufficiently high temperatures during which favorable soil-moisture conditions were present. Summer rains increase the rate of germination, while fall rains, after the mean temperature has dropped, have no apparent effect, nor is the rate affected by the amount of winter rainfall.

Burs incubated at relatively high temperatures invariably showed a higher rate of germination than burs incubated at lower temperatures.

The period from blossoming to maturity of seed is very brief during the season of rapid growth. Burs picked less than 10 days from the time of blossoming failed to germinate, but a large percentage germinated when the burs were permitted to remain on the plant 10 days or more.

Puncture-vine seed apparently requires a resting period after maturity before germination will take place at a normal rate; but after the resting period germination is rapid. Burs of the current season should be held for at least 6 months before being tested for germination.

If the plant is killed or the burs are picked before the natural ripening process is complete, germination is accelerated, apparently

because of interruption of the physiological processes that are responsible for the resting period.

The approximate viability of puncture-vine seed may be estimated by inspection. If the burs are soaked overnight in water and cut open, the number containing apparently sound seed checks fairly closely with a laboratory germination test of the same sample.

Composting of infested manure is suggested for the destruction of puncture-vine seed. A test was made of the effect on puncture-vine seeds of the decomposition of straw and other organic refuse in the making of artificial manure. Seeds in the interior of the compost stack were destroyed, but the exterior was not sufficiently decomposed to kill the seeds.

For the control of growing puncture vine, cultivation and cutting are satisfactory methods, if done often enough to prevent the formation of seed. Heat from a weed torch or from live steam may be used to destroy puncture vine, but burning of green plants without previous treatment is too slow and too expensive to be practical.

A number of chemicals may be used to kill puncture-vine plants, but none except certain petroleum products are known to kill the seeds in all stages.

Diesel oil is more satisfactory for the purpose than other grades because of its availability, its low cost, its high proportion of aromatic and cracked oils, and its ability to emulsify satisfactorily with water when the asphalt content lies within the range of 2 to 5 per cent. It possesses the property of penetrating the burs of puncture vine and killing the seed as well as the plant, even when in emulsion with water, provided the oil is in the external phase of the emulsion. The effectiveness of oil in destroying seeds depends on the completeness of coverage in application.

Soil may be sterilized by means of chemicals to prevent the growth of puncture vine.

The following methods are recommended for the control of puncture vine:

First treat with oil to kill the seeds, if present, without disturbing the vines. Whenever young plants appear, and before the burs form, cut off just below the crown; or spray with oil or any cheap chemical weed killer. Encourage sprouting of seeds remaining in the soil by frequent irrigation during the summer. Do not plow mature burs under.

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